# PROPAGATION PHENOMENA FOR INDOOR WIMAX NETWORKS

## *Implications on Network Isolation and Security*

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Abstract: The impressive success of wireless networks must be supported by research in the radio level, to assure the performance of several networks sharing the same spectrum allocation and the same spatial position. This work provides the data measured along several years of experimental research in the 5 GHz band, including electromagnetic characterisation of different building materials, deterministic indoor radio channels analysis, as well as non deterministic effects as those introduced by people moving or by furniture within a static environment. Such information could be helpful for network designers to predict the network characteristics and to prevent against possible external non authorised access or isolation problems.

# 1 INTRODUCTION

The radio systems deployment is continuously growing in our homes and offices. Particularly, wireless local area networks (commonly known as WLANs) are being significantly developed among worldwide organisations, intended for indoor environments, with several data transmission speeds (Dutta-Roy, 1999) (IEEE Standard 802.16a, 2003). Wireless technology permits a faster deployment and is more flexible than wired solutions.

Ray-tracing techniques have been widely used to simulate the radio channel. After successive improvements and corrections of these (and other) prediction methods, simulation systems have reached a high degree of accuracy. Deterministic effects of the environment (due to building structure) can be modelled, and the precision achieved depends mainly on how accurate the building material characterization is (Cuiñas and García-Sánchez, 2001). However, a good knowledge about the behaviour of indoor environments at wireless LANs frequency bands could not be completed by deterministic simulation, as there are not deterministic elements (furniture, decorative objects, and the movement of people). Radio channel measurements are, then, good solutions to estimate values that are effective to improve the deterministic results provided by ray-tracing simulators.

The proliferation of wireless local area networks (WLANs) could be collapsed due to their own success: the increasing number of systems using the same spectrum allocation could force the active LANs to continuously retransmit data, overloading the spectrum bands as well as collapsing their own transmission capacity.

Another problem is network protection: as users do not need to be physically connected to the system, they could access from places out of the system manager's control.

An exact prediction of coverage areas could help to prevent unauthorised external accesses, as well as to mitigate the interference between adjacent networks by improving the isolation. This paper provides helpful information for radio network designers at 5.8 GHz. The section 2 contains the description of the measurement system used along the research in coordination of different positioning equipments. The section 3 is focused on the electromagnetic characterisation of building materials, giving values that could be used to define indoor environments at deterministic simulators. The results of several radio channel measurement in line of sight (LoS) and obstructed line of sight (OLoS) conditions are presented in section 4. The non-deterministic effects are exposed in sections 5 and 6, devoted to the variability induced by furniture and people in movement, respectively. Finally, the seventh section summarises the conclusions

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extracted from those previously explained experiments.

## 2 MEASUREMENT SYSTEM

A channel sounder based on the swept frequency technique is the main element of the measuring system. This sounder is built around a vector network analyzer (VNA) HP-8510-C, capable of measuring the S parameters of a quadripole in a range up to 50 GHz. The quadripole is constituted by the transmitter antenna, the propagation channel and the receiver antenna, and it is commonly known as radio channel. The $S_{21}$ parameter is the response of that radio channel. Moreover, this $S_{21}$ parameter measured along a frequency range is the frequency response of the radio channel in the considered band.

## 3 BUILDING MATERIAL CHARACTERISATION BY REFLECTION

### 3.1 Measurement Setup and Procedure

The measurement set up for *in situ* characterisation of reflection is configured in a bi-static manner. The transmitter end of the measurement system consists of the transmitter antenna, a standard gain pyramidal horn, fed by a 20 dB-gain amplifier connected the port 1 of the VNA through a 4-meter-long coaxial cable. The receiver end consists of a horn antenna, connected to the port 2 of the VNA by means of a 10-meter-long coaxial cable.

Both antennas are directed to the same point in the reflective surface, called specular point. Whereas the transmitter antenna is set on a rigid mast, the receiver antenna is installed on the top of a mast mounted on a wheeled trolley. The movement of this platform is forced to be circular. The trolley is linked to the surface obstacle by a 2.31 meter rigid bar. The rotation centre is in the surface, just in the vertical of the specular point. Receiver antenna locations are selected along a 180 degree arc, jumping one degree between adjacent ones (Cuiñas et al., 1999). The system is installed on actual walls, performing in situ reflection measurements, as schematised in figure 1.

At each reception measurement point, VNA is set to perform frequency sweeps from 5.72 GHz to 5.88 GHz, taking 801 points at each sweep. The outcomes at each reception point are the result of averaging 10 sweeps, to reduce the effect of noise. Thus, the frequency response, centred at 5.8 GHz, can be obtained at each measurement point.

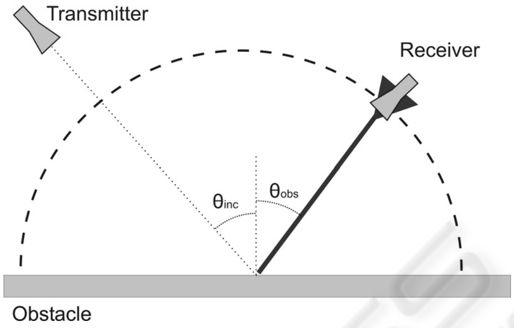

Figure 1: Zenith view of the measurement setup.

The proposed measurement method is an alternative to other techniques also known as *in situ* (Sagnard and El Zein, 2005). In those experiments, the authors used samples of the obstacles, instead of actual walls as in the work here. The results of such experiments have been used to compute the complex permittivity of materials using reflection ellipsometry (Sagnard and al., 2005). Although Fresnel-based analysis techniques (Cuiñas et al., 2007) could not exploit the complete range of incidence angles, they appear to be less sensitive to the adequacy between the geometrical parameters of the setup and the physical properties of the sample.

### 3.2 Results

The table 1 summarises the complex permittivity of each material (metallic surface, brick wall, chip wood panel, and stone and concrete facade) for both incident wave polarisation, measured by the authors following the procedure described in (Cuiñas et al., 2007). These values have been computed using the internal successive reflection method (Burnside and Burgener, 1983), which provides better accuracy in computing electromagnetic characteristics from reflection measurements than the direct application of Fresnel coefficients.

Table 1: Complex permittivity of the different obstacles.

| material | Horizontal polarisation | Vertical polarisation |
|---|---|---|
| Brick wall | 5.03-j0.14 | 4.75-j0.26 |
| Chip wood panel | 3.35-j0.35 | 3.17-j0.04 |
| Stone/concrete wall | 2.04-j0.13 | 4.53-j0.61 |

# 4 INDOOR RADIO CHANNEL MEASUREMENTS

## 4.1 Measurement Setup and Procedure

Indoor wide-band radio channel measurements have been performed with a high precision linear positioning system, and two omnidirectional antennas. The transmitter antenna was stationary while the receiver was being moved along 2.5-m linear paths. Data were taken every one-eighth of a wavelength (Dossi et al., 1996). The positioning system, which consists of a linear table with a millimetre screw along it, improves the precision of the positioning compared to moving the antenna by hand. At each position, complex frequency responses have been measured in a 160 MHz band around 5.8 GHz, with a resolution of 200 kHz, due to the 801 points in the frequency scan. As a consequence, the sounder resolution in the delay domain is 6.25 ns, while the maximum measurable delay is 5 μs.

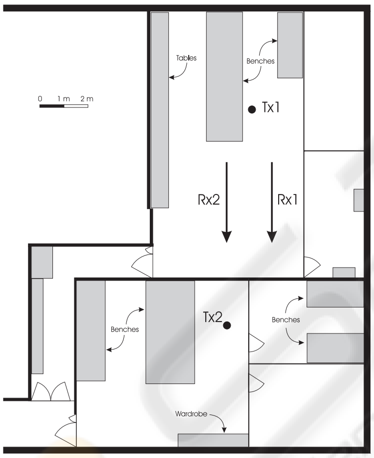

Figure 2: Map of the measured environments. LoS is defined as situation 1, and OLoS as situation 2.

The indoor radio channel frequency response was measured in two different environments, one in LoS condition and the other in OLoS situation. The measurements were taken in research laboratories, with both computers and electronic equipment, and its furniture is the typical of this kind of rooms: office tables and chairs, and laboratory benches. The positions of transmitter and receiver are depicted at Figure 2. During the measurement campaign, the transmitter was fixed at positions Tx1 and Tx2, and the receiver was moved along the lines labelled as Rx1 and Rx2, respectively. The points and paths labelled as "1" correspond to LoS situation and the labelled as "2" to OLoS. The wall that obstructs the propagation channel between both antennas in the second situation is made of bricks and concrete.

## 4.2 Results

The received power as a function of the position can be obtained at any frequency in the measurement range. The received powers measured along the LoS path at 5.72 GHz, 5.8 GHz and 5.88 GHz, are shown in Figure 3.

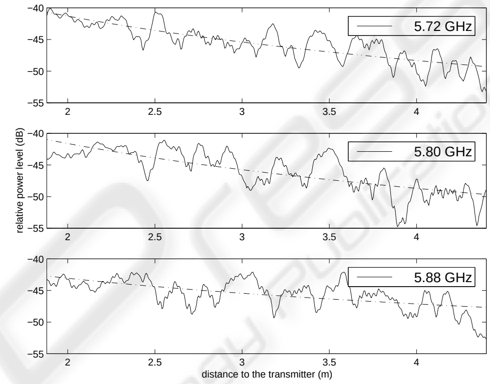

Figure 3: Measured frequency response amplitude, LoS.

The power decays with the distance following a curve of the form $\alpha$ d $^{n}$. The table 2 summarises the values of $\alpha$ and n that better fit the measured data. The main trend is a reduction of the power level as the distance increases.

Fast variations due to multipath propagation appear in the plots, added to that main tendency. These variations follow a Weibull distribution, which is in agreement with (Hashemi et al., 1994).

Table 2: Parameters for the power decay law.

| frequency (GHz) | $\alpha$ | n |
|---|---|---|
| 5.72 | -1.71 | -1.16 |
| 5.8 | -1.73 | -1.18 |
| 5.88 | -1.95 | -0.67 |

The impulse response of the radio channel was also calculated, and the mean square delay and the coherence bandwidth computed. The value below which the delay spread stays for 90% of the positions is 8.8 ns, under LoS conditions. Measured values agree with those reported in (Dersch and Zollinger, 1994) at 2 GHz. For the obstructed situation, the measured time dispersion is 17.4 ns. This value almost doubles that found for the LoS, due to the larger attenuation of the direct ray crossing the brick wall, and the relative higher level of reflections.

The coherence bandwidth is another parameter describing the wideband behaviour of the communication channel. The values over which the coherence bandwidth stays for 90% of the locations at 0.5, 0.7 and 0.9 correlation levels, at both situations, are given in table 3. The OLoS coherence bandwidth is smaller than LoS one.

Table 3: Values over which the coherence bandwidths (MHz) are for 90% of locations in LoS and OLoS situations.

| Correlation level | LoS | OLoS |
|---|---|---|
| 0.5 | 40.0 | 38.7 |
| 0.7 | 23.8 | 11.7 |
| 0.9 | 9.6 | 4.0 |

# 5 QUASI-STATIC EFFECTS ON THE RADIO CHANNEL

## 5.1 Measurement Setup and Procedure

For this experiment, omnidirectional antennas were used at both transmission and reception ends. The figure 4 depicts the hall where the measurement campaign was performed, indicating the location of both transmitting and receiving antennas. Dimensions are expressed in meters. Two series of 421 sets of data each were captured: the first one in an empty environment (as designed in figure 1), and the second one with the room furnished by tables, chairs, wardrobes, and computer and office appliances, in a typical office configuration. No people were allowed to stay in the environment.

## 5.2 Results

Results show that the presence of furniture and decorative objects deteriorates the performance of the radio channel. The amplitudes of the complex envelopes along the 2.5 meter path are depicted at figure 5 for both furnished and unfurnished room, at 5.8 GHz. They are expressed in dB relative to calibration level, obtained by directly connection of transmitter and receiver: so, measurements contain the response of antennas and propagation channel

The spatial variability appears to be modified by the presence of the new elements in the environment. Significant fading events could be due to the high number of signal contributions arriving to receiving antenna following different paths. This is typical of indoor radio channels.

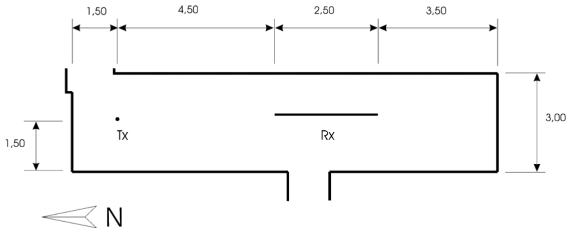

Figure 4: Measurement environment for furnishing effects campaign.

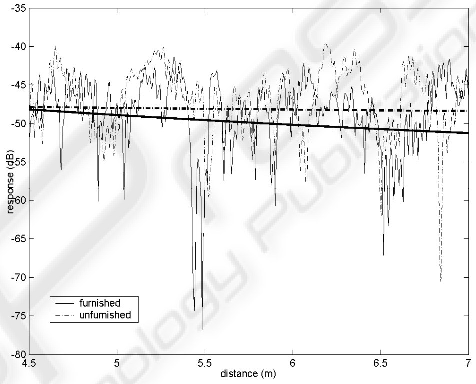

Figure 5: Distance dependence of channel responses in furnished and empty environments.

Results for α and n parameters at each situation are shown in table 4. The rate of decay in the furnished environment seems to be faster than in the empty room.

Table 4: Parameters for the power decay law.

| parameter | Furnished room | Empty room |
|---|---|---|
| α (dB) | -37.72 | -46.02 |
| n | -0.80 | -0.14 |

Table 5: Coherence bandwidth values (MHz) obtained in furnished and empty environments.

| Correlation level | Furnished room | Empty room |
|---|---|---|
| 0.7 | 23.8 | 31.6 |
| 0.9 | 8.4 | 11.8 |

Coherence bandwidths have been also computed from the measured responses. The table 5 summarises the measured coherence bandwidths. When furnishing a room, coherence bandwidth is reduced by 29% at 0.7 and 25% at 0.9.

# 6 VARIATIONS ON THE RADIO CHANNEL PARAMETERS DUE TO PEOPLE MOVING

## 6.1 Measurement Setup and Procedure

At this time, the omnidirectional antennas were placed in static locations during all the measurement period. Transmitting antenna was situated in an elevated location (at 2.5 meter high over floor level), and receiving antenna at 1.5 meters.

Snapshot data, gotten at each 10 seconds, were caught in series of 1 hour duration. At every environment, six series of data were taken during work time, which means six hours in total, and another series during night, when it is assumed no people is working. No movement of people was forced or induced, being all traffic due to working or personal needing. The variations are only due to changes occurred in the environment along time.

Four different environments were used to perform the experience: a computer lab, a research lab, a corridor and a hall. The LoS conditions were guaranteed in every environment at every time, except when one or more people obstructed the channel between both antennas.

## 6.2 Results

The box plots computed using the measured data at the hall are shown in figure 6. In this plot, the left hand graphic corresponds to people in motion during work time, whereas the right hand was obtained during night time, with no people.

The box for quiet environment is thinner than for the dynamic moments, which means that people in motion introduce an important amount of variation in received power level. The median value for people in motion is almost the same than in the static room, which indicates that no attenuation is induced by the dynamic circumstances. Besides, the in-motion plot shows lower outliers (represented as crosses in the figure), which indicate a deeper fading situation.

The median values are almost the same for quiet and in-motion situations at each environment, but the time variability of channel response grows with movement of people. This can be concluded by observing the inter quartile range (IQR) values for every environment. Outliers occur mainly in people-in-motion situations. This indicates that extreme values of received power could occur with higher probability when people are moving inside the environment than when the space is quiet.

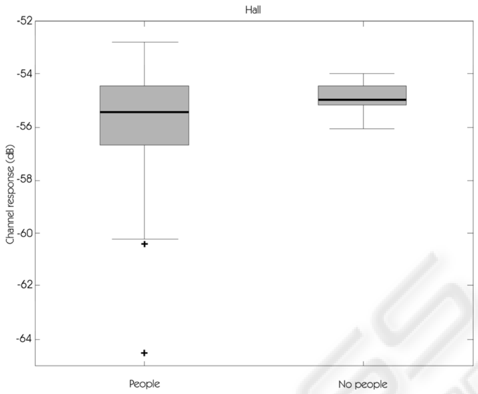

Figure 6: Comparison between daytime (people) and night time (no people) situations at the hall.

The table 6 summarizes the results for the four environments. Similar effects can be observed in the four environments. Median values are almost the same for moving and static situation, showing a trend of slightly incrementing the attenuation in occupied rooms. The time variability is increased when people moves within the room. Increments in time variability can be evaluated in between 14%, in the computer lab, and 200%, in the hall. There may be more persons moving, staying and crossing along in the hall, which is a common area, than in the computer lab, where only researchers working there can access the facility. So, a relationship could be established: the more people and movement, the more time variability is reflected in the power level.

Table 6: Comparison of statistics corresponding to different environments for people movement.

| | Median (dB) | | IQR (dB) | | Outliers | |
|---|---|---|---|---|---|---|
| People | yes | no | yes | no | yes | no |
| Corridor | -57.5 | -57.2 | 1.5 | 0.9 | yes | no |
| Research lab | -63.5 | -62.4 | 2.2 | 1.4 | yes | no |
| Hall | -55.4 | -55 | 2.0 | 0.6 | yes | no |
| Computer lab | -62.3 | -62.3 | 1.6 | 1.4 | yes | no |

The results appear to show that the movement of people has small influence in long-time average response of the channel, although it could be strongly influent in short time periods.

# 7 CONCLUSIONS

This work provides the data measured along several years of experimental research in the 5 GHz band, including electromagnetic characterisation of different building materials, indoor radio channels analysis, as well as non deterministic effects as those introduced by people moving or by furniture within an static environment.

The complex permittivity values provided for two orthogonal polarisations and three walls of different kinds could be used in simulation tools to define indoor environments constructed by typical building materials.

A power decay law as a function of distance between transmitter and receiver is also provided at different environments in both LoS and OLoS conditions. Fast variations due to multipath propagation appear, added to this main tendency. These variations follow a Weibull distribution.

Broad band radio channel parameters, as time delay and coherence bandwidth, are presented in this work.

Moreover, non-deterministic effects have been also measured and reported. These added contributions, which are due to the presence of furniture or to people in motion within the environment, could be modelled as a random contribution added to the deterministic one.

Results show that the presence of furniture and decorative objects deteriorates the performance of the radio channel. The attenuation with distance grows, as well as new fading events appear, as the presence of new elements in the environment produces reflection of waves and scattering. When furnishing a room, coherence bandwidth is reduced by 29% at 0.7 and 25% at 0.9 correlation levels, probably due to the new multipath components that are received as a result of the presence of more scatterers in the environment.

The movement of people seems to have small influence in long-time average response of the channel (median received power), although it could be strongly influent in short time periods. Besides, punctual highly constructive or deeply destructive interference can occur when people acts in the environment.

This information could be helpful for network designers to better predict the network performance and to prevent possible external non authorised access or isolation problems, as the more exact the planning is, the less coverage problems could appear.

# ACKNOWLEDGEMENTS

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